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Characterization of Swiss Spent Nuclear Fuel: a neutronics integrated approach

TM on Spent Fuel Characterization, IAEA, Vienna, Austria,
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Summary

- The CMSYS database and CS_2M method (modelling)
- Validating SNF with PIE data: the U1 example (destructive/non destructive analysis)
- Uncertainty for SNF due to nuclear data (modelling)
- Data and knowledge management
- Conclusion

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CS_2M

- CS_2M: CASMO – SIMULATE – SNF – MCNP
  Systematic and consistent neutronic approach for Spent Nuclear Fuel, from power plants to long-term repository

- Goal: Spent Nuclear Fuel assessment (content) taking into account their irradiation life and cooling in a realistic way

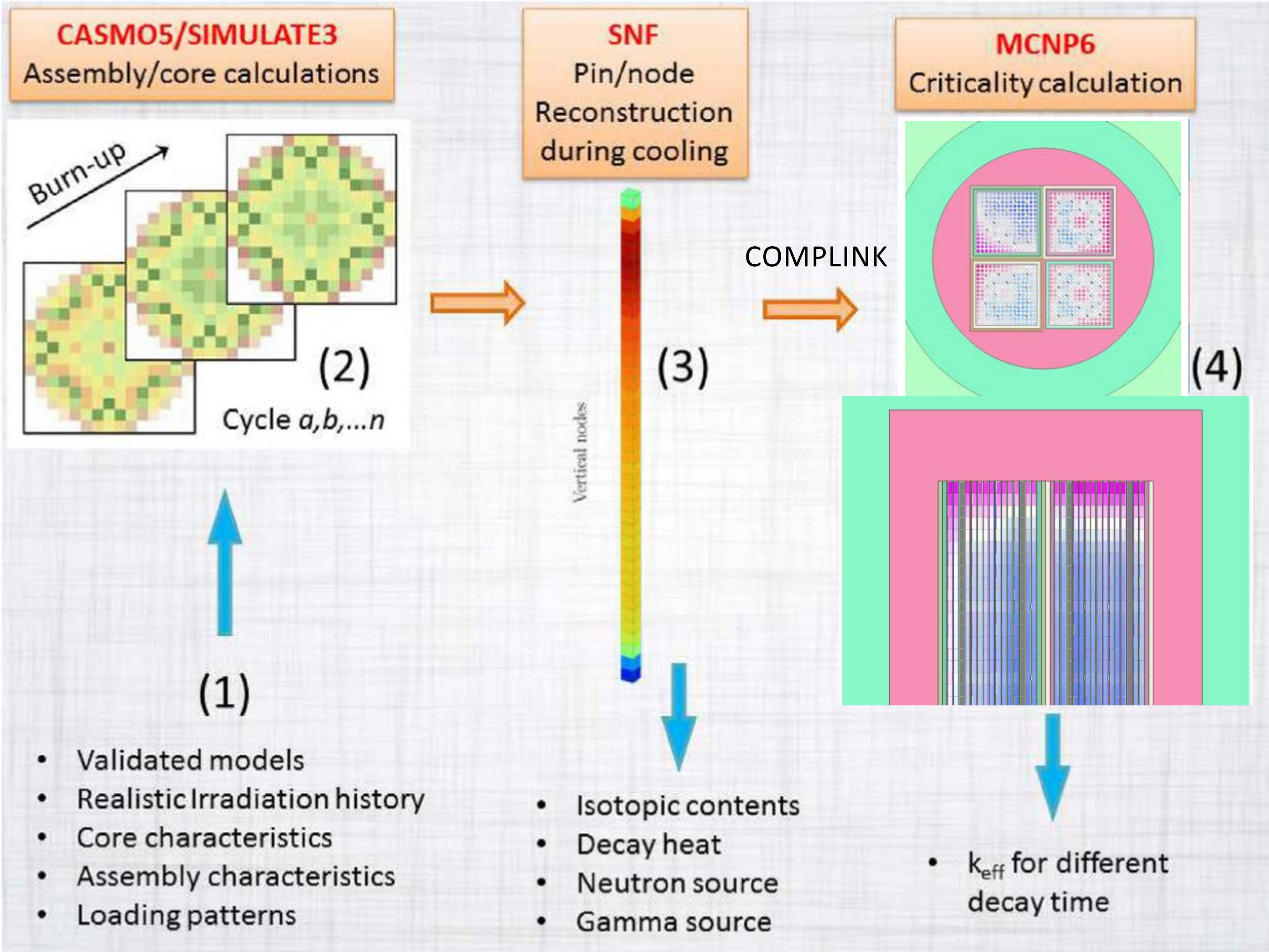
- Solid ground: Large amount of information + experience is already at the LRT
  - Fuel history from utilities (>40 years of operation)
  - State-of-the-art tools (CASMO + SIMULATE + Monte Carlo)
  - Validated models (CMSYS for the 5 Swiss reactors) + SNF (spent nuclear fuel code)
  - Nuclear data control
  - Applied for Spent Fuel knowledge (source term, canister, criticality…)

- Method: only “connecting the dots” (or linking the above)

- Output: consistent (from the same source) loading curves + decay heat + radiotoxicity + fuel content for all Swiss nuclear fuels (12 000 assemblies and for each segment)

CS_2M: Just linking existing tools

- Based on core licensing information



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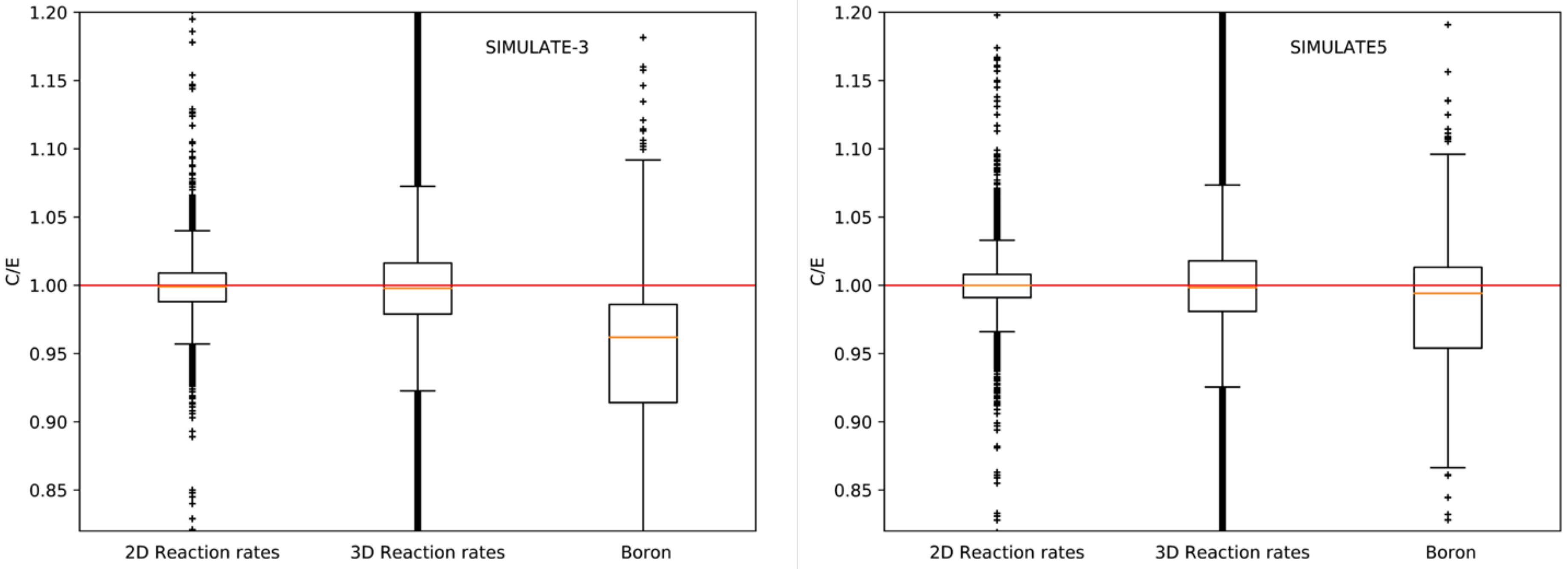
Modelling: CMSYS

- Validated CASMO + SIMULATE models for the Swiss cores
- Using boron and incore data

	KKB1	KKB2	KKG	KKM	KKL
cycle	16-44	12-45	1-40	19-46	1-35
Assemblies per core	121	121	177	240	648
Rod per assembly	196	196	225	64	64
Vertical nodes	20	20	40	25	25
Volume	≈19 Gb	5 Gb	17 Gb	27 Gb	20 Gb

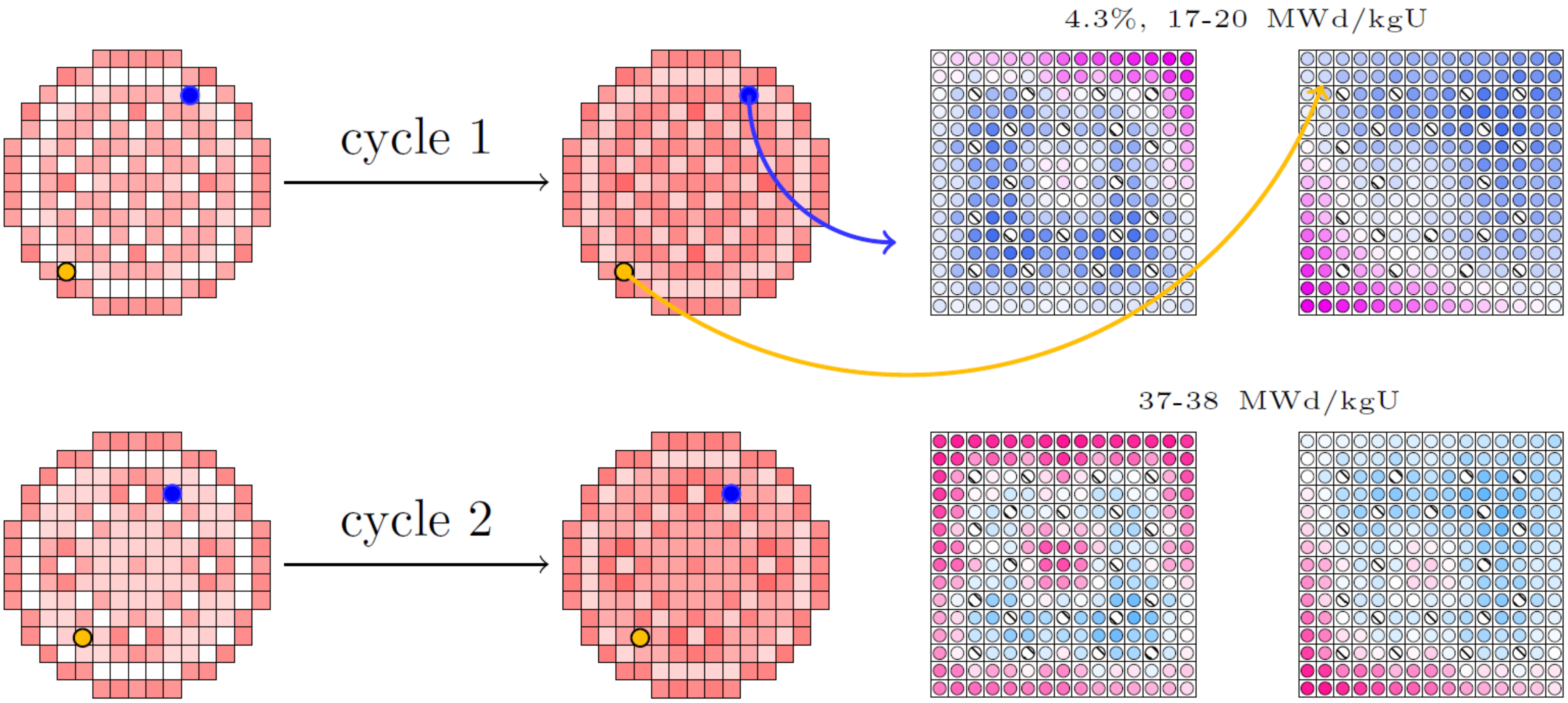
SIMULATE5/CASMO5 validation

- Global comparison for one Swiss PWR



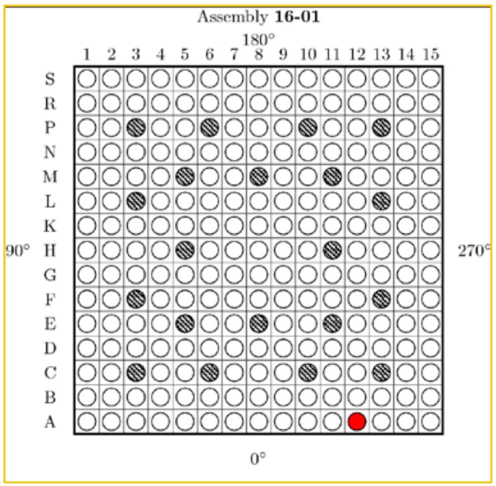
CS$_2$M: Importance of core follow-up

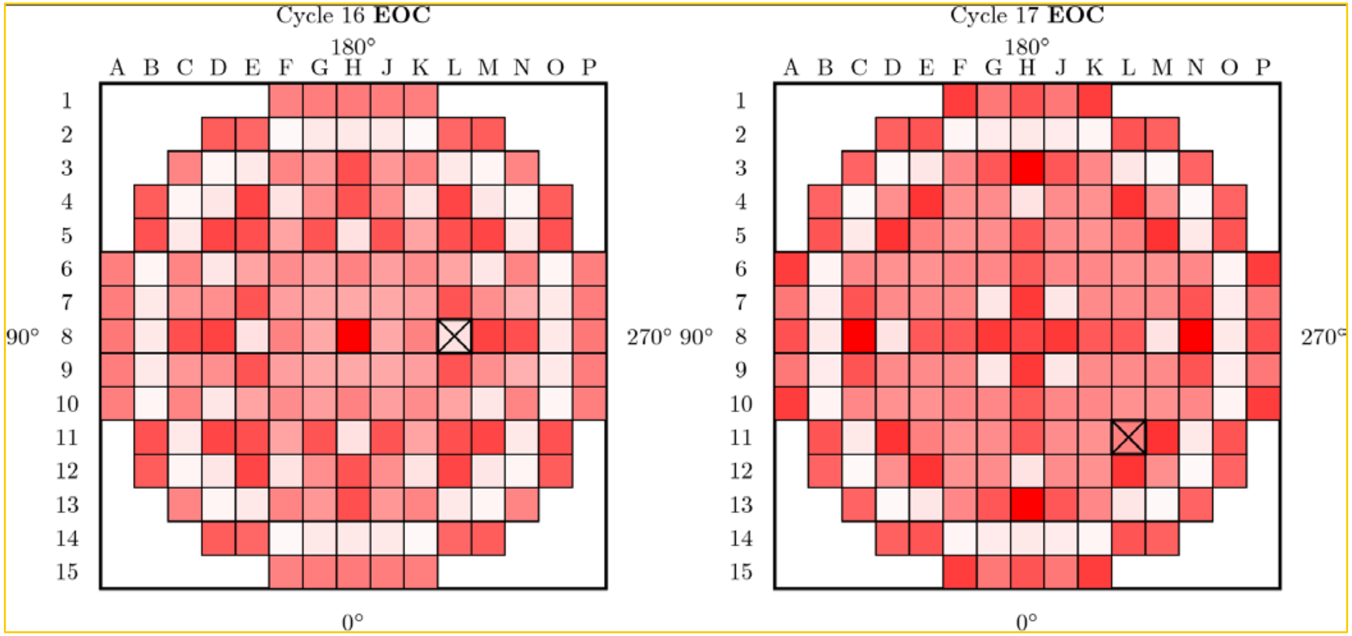
- Example of knowledge of assembly irradiation



SNF validation: Experimental knowledge on U1

- U1 sample (also known as UR7) is one of the 13 LWR-PROTEUS Phase II samples, analyzed for PIE isotopic contents
- It comes from the assembly 16-01 irradiated at Gösgen during 2 cycles (680 days):
  - Cycle 16: (343 days) - Shutdown time: 28 days Cycle 17: (337 days)



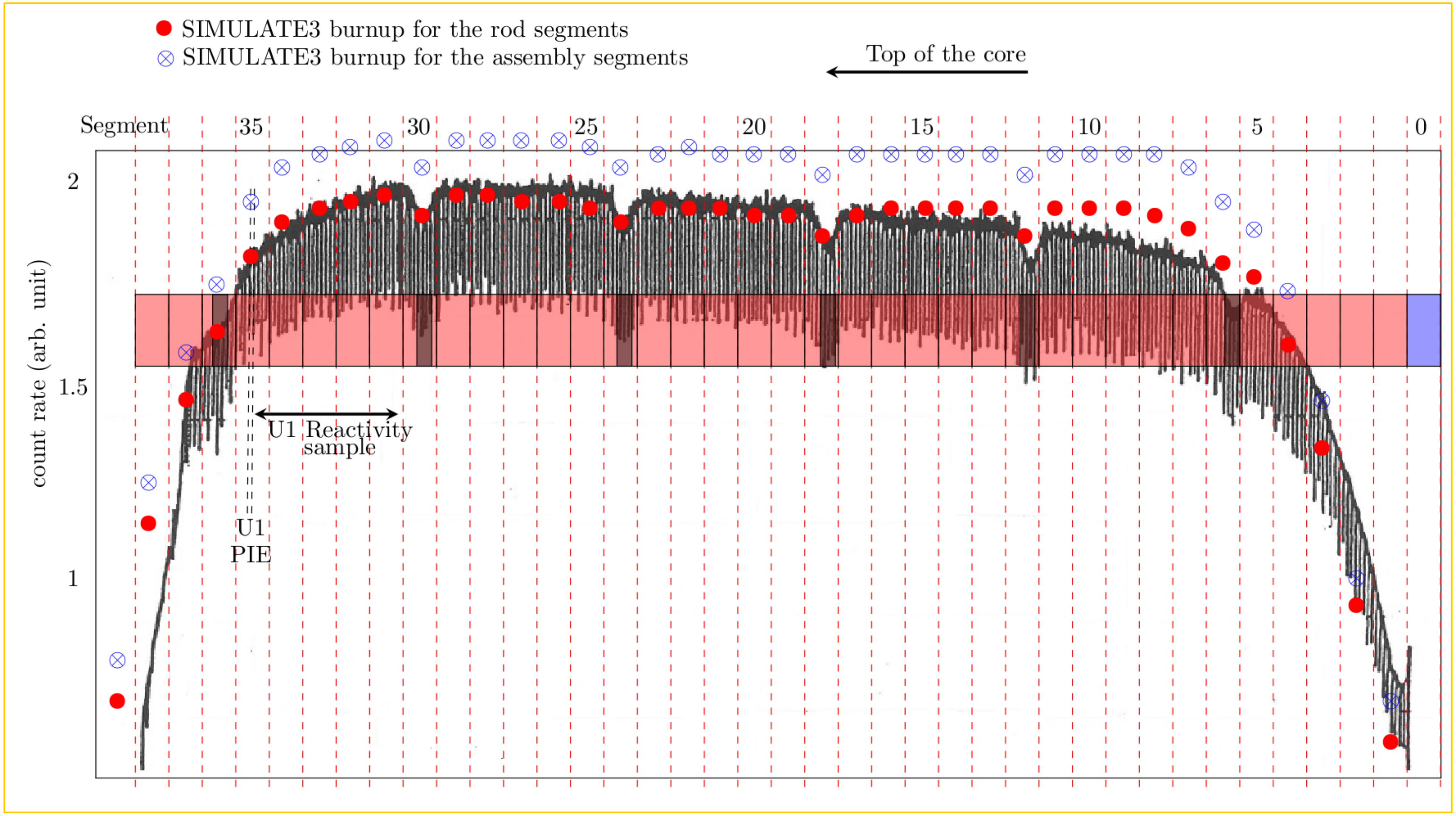


Location of the assembly 16-01 containing the U1 sample, for cycle 16 and 17. The position of the assembly 16-01 is indicated by a cross. The colours are proportional to the assembly burnup obtained from SIMULATE-3 at the end of cycle (EOC).

- This work is performed in collaboration with M. Seidl and J. Basualdo from PreussenElektra

CASMO/SIMULATE validation for U1

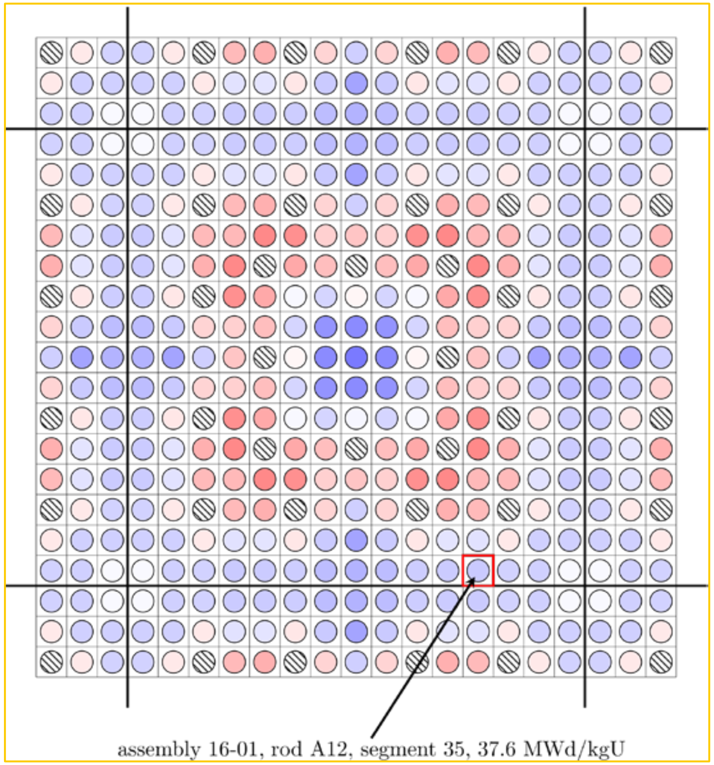
- A12 rod power profile



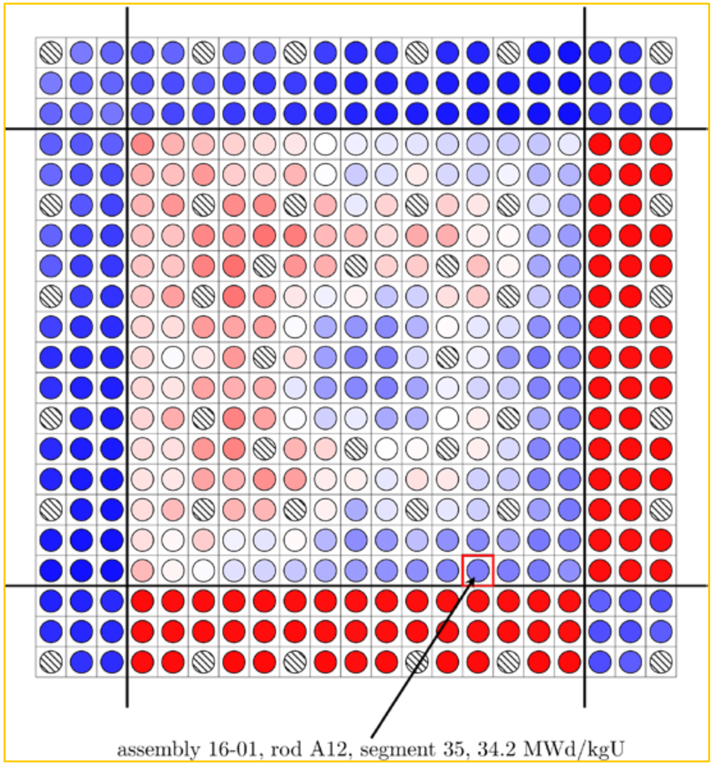
Comparisons of the rod measured gamma-scan profile and the calculated burnup profiles for the full assembly 16-01 (blue circles) and the rod A12 (red circles).

CS_2M: advantage of fuel core vs. single assembly

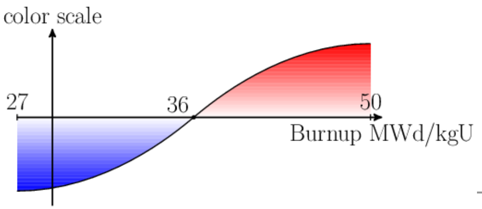
- With CS_2M, CASMO and SIMULATE are combined for pin/segment calculations
  - realistic irradiation history is considered + account for neighboring assemblies.
  - This is a major advantage compared "single assembly calculation" (only lattice code)



CASMO

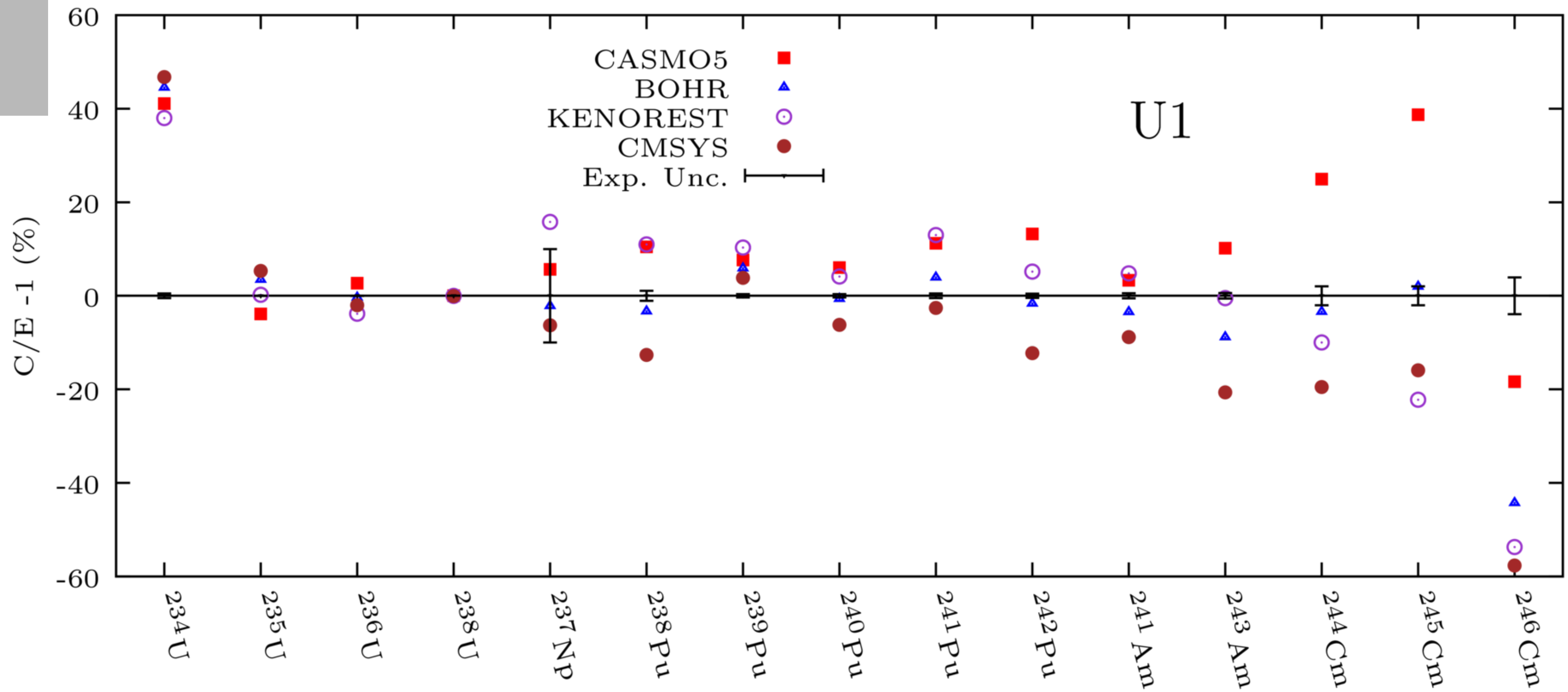


CS_2M



New SNF calculations for U1

- <u>U1 calculation validation for PIE (Better C/E, different sample burnup)</u>



CMSYS	U1 burnup:	34.2 MWd/kgU,	average C/E-1= +1.5 %
CASMO5	U1 burnup:	37.6 MWd/kgU	average C/E-1= +16.8 %
BOHR	U1 burnup:	35.8 ± 1.8 MWd/kgU	average C/E-1= +7.6 %
KENOREST	U1 burnup:	35.9 MWd/kgU	average C/E-1= +10.3 %

Example of previous validation: ANE94(2016)603

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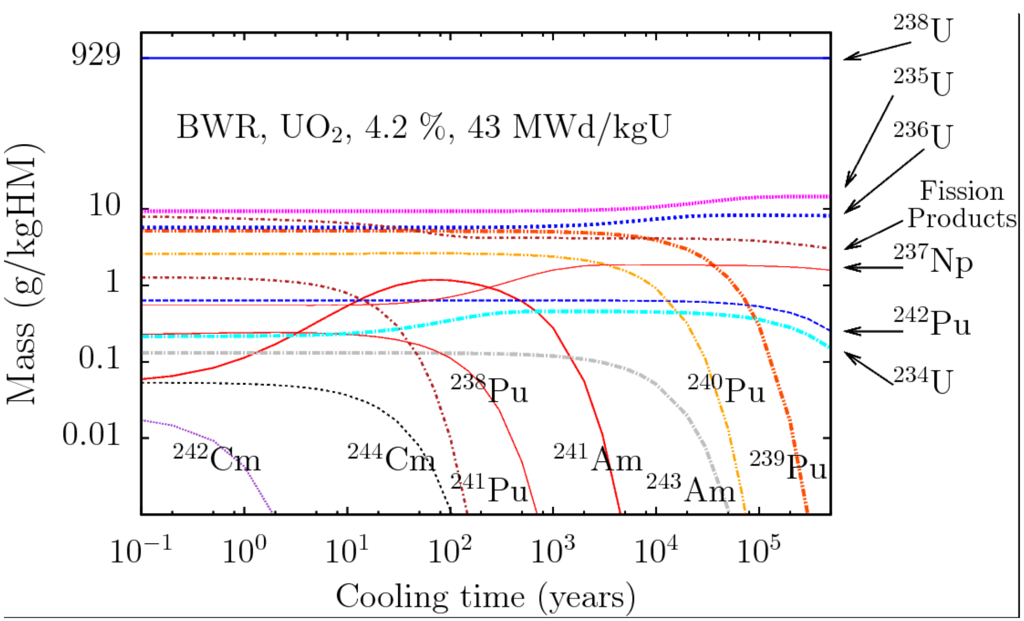
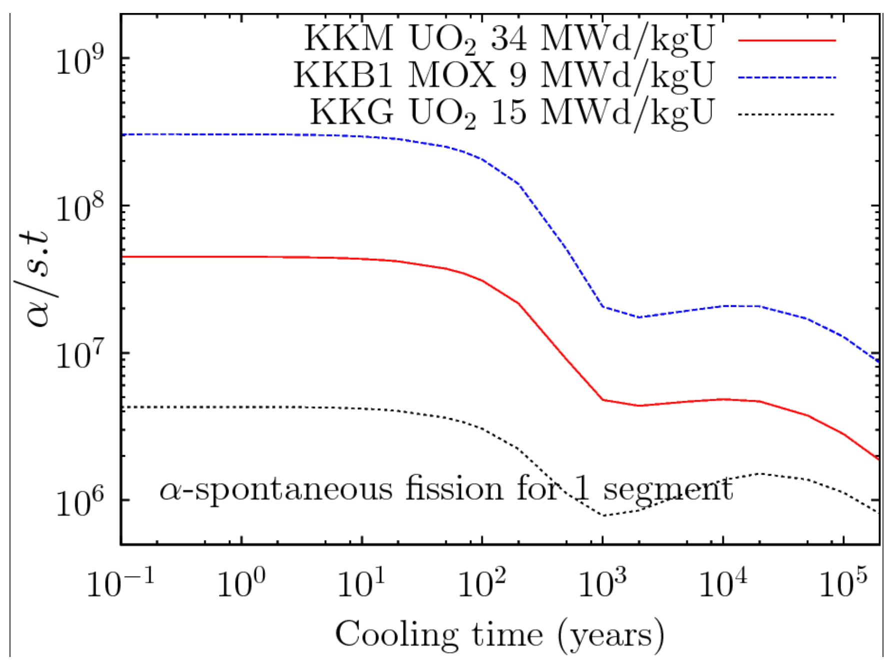
CS_2M: from neutronics to fuel behavior

- For each core, cycle, assembly, rod, segment:
  1. actinides + fission products + decay heat + neutron source
  2. during cycles and
  3. for any cooling time
- Ideal for providing inputs to fuel behavior codes with decay heat, gamma/alpha emission for each segment

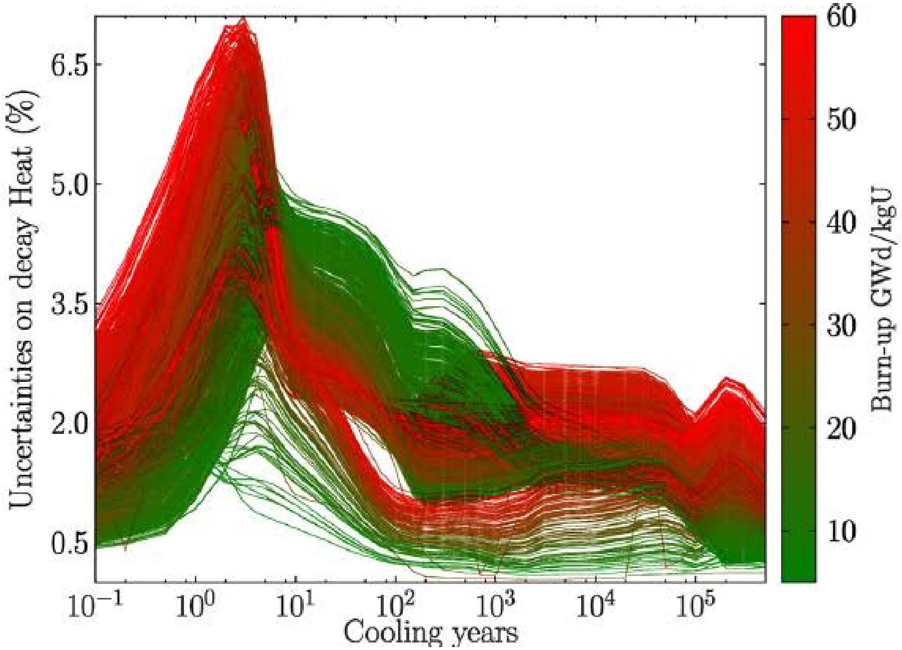


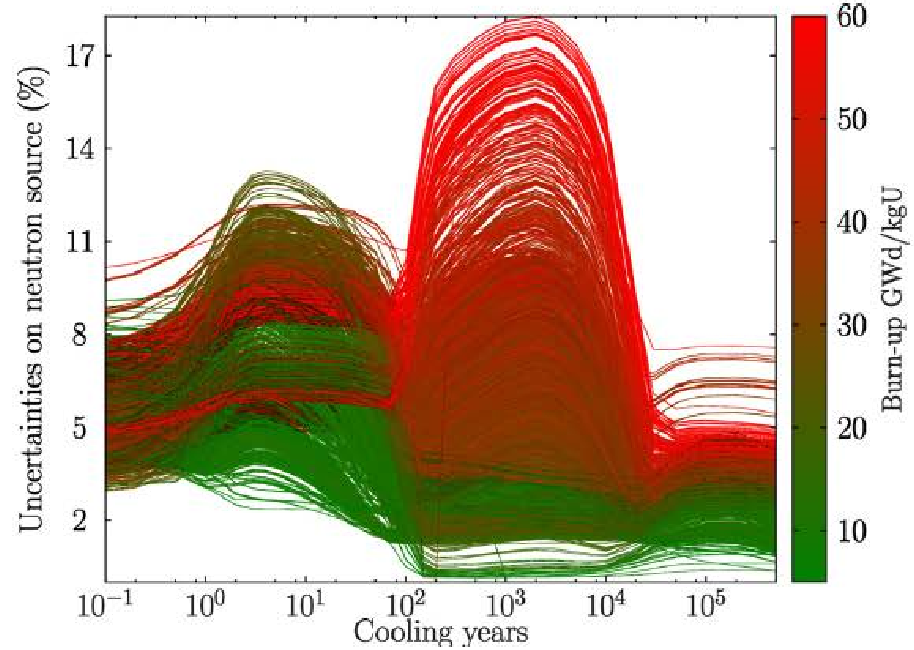


CMSYS + CS_2M + UQ

- Propagation of uncertainties for each quantities (*e.g.* due to nuclear data)

- Why ?
  - Nuclear data were proven to have an important impact on spent fuel quantities
  - Necessity for “Best estimate plus uncertainties” approach
- Example for decay heat and neutron source (PWR+BWR)





CMSYS + CS_2M + UQ

- Example for a BWR: assembly burnup and decay heat (sampling XS and FY)

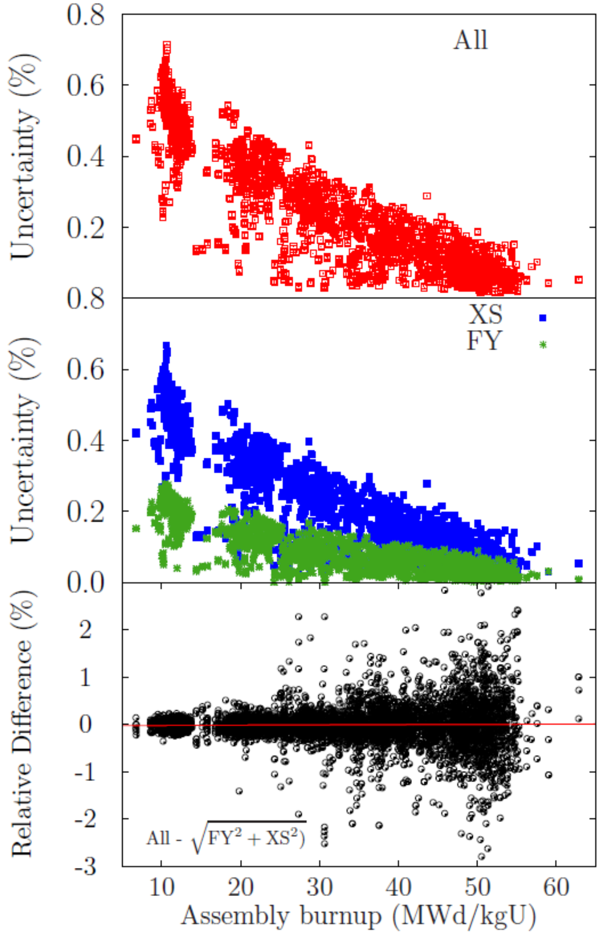


Fig. 8: Uncertainties due to nuclear data on the average assembly burnup; Top: all nuclear data sampled together; Middle: FY and XS sampled separately; Bottom: differences in terms of relative uncertainties between sampling together and separately. The red line is a fit of the differences. Each dot indicates a specific assembly at the end of a specific cycle.

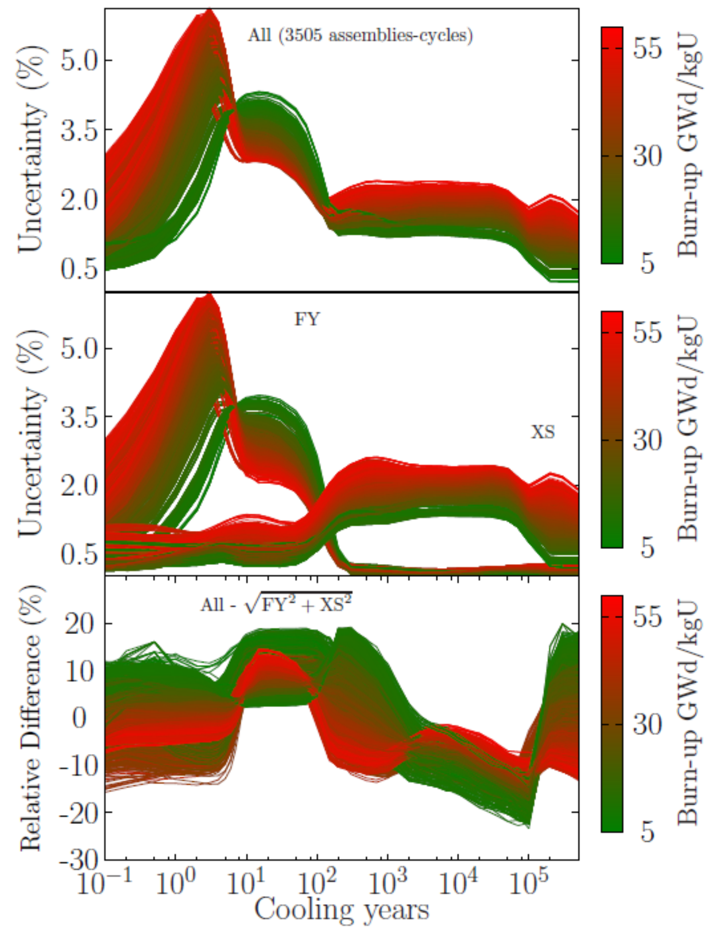
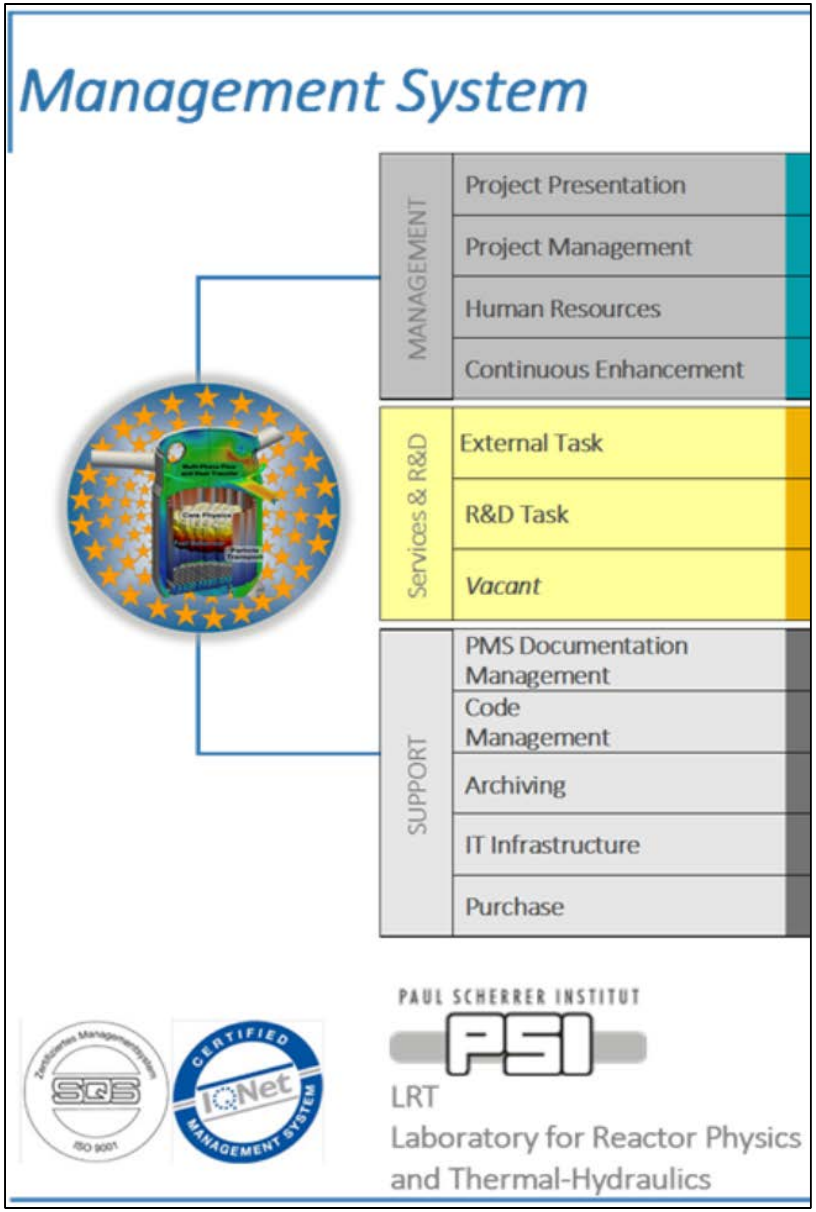


Fig. 11: Uncertainties due to nuclear data on the assembly decay heat; Top: all nuclear data sampled together; Middle: FY and XS sampled separately; Bottom: differences in terms of relative uncertainties between sampling FY and XS together and separately. Each curve represents a specific assembly.

Data and knowledge management

- Necessary inputs: all cycle information from the utilities
- Necessary tools: to be able to get pin/segment source term information (our choice: CASMO/SIMULATE/SNF/MCNP or CS2M)
- Output: isotope inventory, decay heat, neutron/gamma emission for all pin/segment
- Sharing of data: difficult due to the proprietary aspects of the information
- Record management: under ISO9001



Data and knowledge management

- The amount of data for SNF can be large to “extremely” large
- Moving towards BEPU requires better data handling

	KKB1	KKB2	KKG	KKM	KKL
cycle	16-44	12-45	1-40	19-46	1-35
Assemblies per core	121	121	177	240	648
Rod per assembly	196	196	225	64	64
Vertical nodes	20	20	40	25	25
Volume (1 cooling time)	~~19~~ 220 Gb	~~5~~ 260 Gb	~~17~~ 950 Gb	~~27~~ 175 Gb	~~20~~ 590 Gb
File number	$\approx 10^7$	$\approx 10^7$	$\approx 10^8$	$\approx 10^7$	$\approx 10^8$
	With uncertainties (calculations x 300)				
Volume (1 cooling time)	66 Tb	78 Tb	285 Tb	52 Tb	177 Tb
File number	$\approx 10^9$	$\approx 10^9$	$\approx 10^{10}$	$\approx 10^9$	$\approx 10^{10}$

Conclusion

- Our validated models + CASMO+ SIMULATE +SNF (CMSYS + CS_2M) allows to calculate (and later validate) spent fuel characteristics (content, source terms) and connect with various projects.
- SNF is one of our key tools (with CASMO/SIMULATE), at the basis of our work for core physics, spent fuel, and later links to transient and fuel behavior.
- Strong link with the EURAD WP8 (Spent Fuel Characterization)
- Used to provide detailed neutronics information in support of the NAGRA (responsible in Switzerland for back-end of the SNF)

Wir schaffen Wissen – heute für morgen